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MEMORANDUM REPORT ARBRL-MR-02834

LEVEL II

(Supersedes IMR No. 528)

9 Final rept.

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INTERIOR TEMPERATURE MEASUREMENTS ON XM650E4 RA PROJECTILES AT YUMA PROVING GROUND IN JUNE 1976.

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11 April 1978

12 36p.

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

16 1W664603D663

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393 471

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MEMORANDUM REPORT ARBRL-MR-02834✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INTERIOR TEMPERATURE MEASUREMENTS ON XM650E4 RA PROJECTILES AT YUMA PROVING GROUND IN JUNE 1976		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) W.H. Clay V. Oskay		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory (ATTN: DRDAR-BLL) Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1W664603D663
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory (ATTN: DRDAR-BL) Aberdeen Proving Ground, MD 21005		12. REPORT DATE APRIL 1978
		13. NUMBER OF PAGES 42
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This Memorandum Report supersedes IMR No. 528 dated October 1976.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

XM650E4 RAP
Bulkhead Temperature Measurements
Yawsondes
Solar Aspect Angle Data
Spin Data

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two 8-inch rocket-assisted XM650E4 projectiles were fired at Yuma Proving Ground, during June 1976, to determine interior temperature of the warhead. The temperature sensors were located on the interior wall of the warhead base. The projectiles were also instrumented with trisondes to determine their flight behavior.

One of the rounds, fired at Zone 9 from the M110A1 weapon, did not transmit any data. TR 296, which was fired from the M110 at Zone 7, transmitted both the

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20. ABSTRACT (Cont'd.)

temperature and trisonde data. Flight data from the trisonde show a well-behaved projectile.

The data from the temperature sensors of TR 296 indicate that there is a 35-second time lag between the ignition of the rocket motor and the start of bulkhead temperature rise. Data also show a uniform bulkhead temperature at the start and conclusion of the flight with no indication of hot spots. The total temperature rise for the bulkhead was about 8°C, reaching a level of 32°C at impact.

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I. INTRODUCTION

Two XM650E4, 8-inch projectiles instrumented with temperature sensors and a telemetry package were fired as part of a yawsonde test program at Yuma Proving Ground, Arizona (YPG) in June 1976. Both shell were fired at 53° elevation with rocket on, one from the M110 howitzer at Zone 7 and the second from the M110A1 at Zone 9. Temperature sensors were mounted at the base of the warhead interior to measure the temperature rise at the wall produced by the burning of the rocket motor. The rocket motor ignites at about seven seconds after launch and burns for about four seconds at temperatures of approximately 2800°C. There was some concern that the payload of the shell might experience adverse heating effects.

The two temperature-instrumented rounds were also equipped with BRL yawsondes and spinsondes to measure the yaw and spin histories of the shell. This report describes temperature measurements as well as the yaw and spin history for the round fired at Zone 7.

II. INSTRUMENTATION

Each XM650E4 projectile body was instrumented with nine temperature gauges at five locations: two thermistor gauges at each of locations 1 through 4 and a thermocouple at location 5. Figure 1 is a sketch of the XM650E4 body, showing the surface to which the nine gauges were attached. Figure 2 shows the relative orientations of the five locations. Two thermistor gauges were used at locations 1 through 4 to provide coverage for a wider range of temperatures. One thermistor at each position gave accurate coverage from 20°C to about 120°C with maximum sensitivity at 70°C. The other thermistor was set to measure temperatures between 80°C and 180°C with maximum sensitivity at 140°C. The thermocouple at position 5 could measure a temperature range from 0° to 260°C.

A. Thermistor Gauges

The temperature gauges used at positions 1-4 consisted of 13-mil diameter, glass-coated thermistor beads whose leads were soldered to a thin, copper-clad, phenolic washer. This construction is shown in Figure 3a. A piece of tape was mounted on the bottom of the wafer and the thermistor bead was attached to the sticky surface of the tape to hold it while the bead's lead wires (1-mil diameter) were soldered to contacts on the top surface of the washer. A heavier set of lead wires were attached to these contacts in order to connect to the telemetry package which was located away from the temperature gauges in the shell. Two beads were attached in this manner to each washer. The center of the phenolic washer was filled with a high-thermal-conductivity encapsulant to protect the thermistor during launch. The thermistor fixtures were then put in molds and further potted, using an encapsulant with a lower thermal conductivity. The resultant module is shown in Figure 3. The thermistor fixture measures about 12mm in diameter and about 25mm long, with the thermistor beads flush with the bottom surface, insuring good thermal contact between the thermistor bead and the metal surface to which it would be mounted.

The rear walls of the interior of the shell were spot-faced to a depth of 1mm (0.040") at the locations and orientations shown in Figures 1 and 2. The thermistor modules were attached to the shell at these locations, using a thin layer of the same high-thermal-conductivity potting that directly surrounds the beads.

B. Thermocouple Gauge

The thermocouple located at position 5 was a commercial chromel-constantan unit and was electrically compensated to 0°C. The thermocouple junction was encapsulated in a fixture similar to that for the thermistors and mounted in a similar manner.

All of the thermistors and thermocouples were calibrated prior to mounting into the shell. A typical resistance versus temperature calibration is shown in Figure 4. Since the signals from thermocouples are in the millivolt range, amplification was necessary. Figure 5 shows a plot of the amplifier output versus temperature for the thermocouple.

C. Electronic Package

The thermistor gauges formed one-half of a voltage-divider network. The circuit for a single position is shown in Figure 6. The resistors R_A and R_B were fixed resistors whose values were chosen so that voltage V_A would have the greatest change with temperature around 70°C while V_B would be most sensitive around 140°C. In this manner, a wide range of temperature coverage at a particular location was achieved. A plot of the voltage-temperature characteristics for the thermistor is shown in Figure 7. The dashed lines show the area of greatest sensitivity with temperature for each of the gauges at a given position.

The signals from the thermistor-voltage dividers and the thermocouple amplifiers were sampled by an electronic commutator at the rate of 10 samples per second. Thus, a given temperature gauge was sampled every 0.1 second. The commutator output was made to frequency modulate a 70 kHz voltage-controlled oscillator (VCO) and was subsequently telemetered to ground receiving stations via a radio-frequency oscillator located in the nose of the ogive. A tracing of the commutator wave-form obtained from one of the test rounds at Yuma is shown in Figure 8. The channel assignments are indicated in the figure.

A block diagram of the electronic package is shown in Figure 9 and a sketch of the assembly of the shell is shown in Figure 10. The transmitter, yawsonde, spinsonde, and all VCOs were located in the fuze portion of the shell while the remainder of the electronic package and the battery power supplies were located in the body of the shell. Battery power and the commutator signals were sent to the telemetry package in the nose via a connector-interface, as shown in the schematic of Figure 10.

D. Trisonde Package

In addition to temperature instrumentation, each test projectile was also equipped with a trisonde. Electronic and mechanical relationship of the trisonde to the temperature gauges is shown in Figures 9 and 10, respectively. Trisondes were included in order to monitor spin and yawing histories of the projectiles. A trisonde is the combination of a spinsonde and a yawsonde each modulating a different VCO, as shown in Figure 9.

A spinsonde consists of a single silicon solar cell that generates a voltage whenever illuminated by the sun once every revolution of the projectile. In order to minimize the contamination of spin data by the projectile's yawing motion[1], the slit of the spinsonde is mounted parallel to the shell's axis of symmetry.

The yawsonde consists of two silicon solar cells mounted behind slits on the surface of the fuze contour[2]. The voltages generated from these silicon cells form a pulse train that is used to frequency modulate a VCO. The sunsensor pulses are then amplified and transmitted to the ground receiving stations through an FM/FM transmission link. During this program, the output of the yawsonde VCO is multiplexed with the outputs of the other two VCOs (temperature and spin) in a mixer amplifier. Since the slits of a yawsonde are oriented at an angle relative to the shell's axis, the phasing of the sunsensor pulses are related to the shell's yaw angle. This relationship had been determined during the calibration of the unit. During the data analysis, the observed phase relationship is converted to complementary solar aspect angles, sigma-n, through the calibration data. (The complementary solar aspect angle is defined as the angle between a normal to the shell's axis and the vector from the sun to the shell.)

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1. C.H. Murphy, "Effect of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," Ballistic Research Laboratories Memorandum Report 2581, February 1976. AD B009491L.

2. W.H. Mermagen and W.H. Clay, "The Design of a Second Generation Yawsonde," Ballistic Research Laboratories Memorandum Report 2368, April 1974. AD 780064.

III. FIRING CONDITIONS AND TEST RESULTS

The two XM650E4 shell were fired with rocket on at Yuma Proving Ground in June 1976. Table 1 summarizes the firing conditions of the two rounds instrumented for temperature measurement.

Table 1. Firing Conditions For Two XM650E4 RA Projectiles Instrumented With Temperature Gauges

Date	BRL No.	Tube Round No.	Charge	QE	Weapon
23 June 1976	1152	296	Z7 RA	950 mils	M110 (Tube #7652)
24 June 1976	1151	840	Z9 RA	950 mils	M110A1 (Tube #27)

Both of the rounds were preconditioned to about 21° Centigrade before firing.

The first round, TR 296, was fired on June 23 at Zone 7 and an elevation of 950 mils out of the M110 weapon. This weapon has a twist of 1 in 25. The transmitter and electronic package functioned well. Tube round 840 was fired the following day at Zone 9 out of the M110A1 weapon which has a twist of 1 in 20. Tube round 840 failed to transmit, and no data, temperature or yawsonde, were obtained. Figures 11 and 12 are smear photographs of TR 296 and TR 840, respectively, taken as the shell exited the muzzle. Stripes had been painted on the shell after they were assembled. It is clear from the smear photographs that the ogives on both rounds had tightened during launch. However, the photograph of TR 840 (the round with the higher velocity and higher twist) shows that the ogive has tightened up considerably (approximately 15° of rotation). This degree of movement past the point to which it was assembled probably caused the connector interface between the body and fuze to fail, a possibility that would explain the lack of RF transmission due to loss of battery power.

A. Temperature Data From TR 296

One frame of the commutated temperature data from TR 296 is shown in Figure 8. The signals from the various gauges are identified in the figure. Note that the signals from gauge A, position 3 and gauge B, position 4 are at the 0.0 volt reference level. This indicates that the thermistor gauges or lead wires for these gauges failed. The 50% level (2.5 volt reference) would correspond to 70°C for the A gauges and to about 140°C for the B gauges. A 5-volt swing in voltage for the thermocouple would correspond to a 260°C swing in temperature. The 5-volt reference and the 2.5 volt reference are internal to the commutator. The commutator was also used to monitor the two redundant batteries used to power the telemetry package (battery voltage #1 and battery voltage #2) and the 5-volt regulator used for the thermistor voltage divider circuits (5 volt reg.). The sample data frame shown in Figure 8 was taken about mid-way in the flight of TR 296. The temperature indicated by the signal levels from the gauges in the frame is about 22°C. Table 2 gives a tabulation of temperature versus time from the A gauges at positions 1, 2, and 4 and for the thermocouple at position 5. The results from the B thermistor gauges are not presented because they are not very accurate for the low temperature indicated. These results are plotted in Figure 13.

Table 2. Temperature Versus Time For TR 296

Time	Temperature (°C)			
(sec)	Pos 1	Pos 2	Pos 4	Pos 5 (Thermocouple)
.1	23	24	24	--
1	21	22	24	29
5	22	22	23	28
10	22	23	24	28
15	23	24	24	30
20	22	24	24	30
25	22	24	24	28
30	22	24	24	28
35	23	23	24	28
40	23	23	25	30
45	23	24	26	30
50	23	24	26	28
60	26	28	30	36
70	25	28	31	36
80	25	30	31	36
83.7	28	31	34	38

The estimated error of the temperature readings is about 3 to 4 degrees for the thermistors and about 5 to 6 degrees for the thermocouple. The data indicate that the interior wall at the base of the shell remains at or close to the preconditioned temperature for most of the flight, with a slight increase in temperature towards the end of the flight. The discrepancies in temperature between the thermistors and the thermocouple may be due to the larger inaccuracies in the thermocouple readings at these relatively low temperatures or may be due to a real temperature distribution at the rear wall of the shell. AGC records from the MPS-25 radar indicate that the rocket motor turned on at about seven seconds after launch and burned for about four seconds. There was no change observed in the wall temperature during the time the rocket motor was on.

It should be noted that a static test was conducted by Picatinny Arsenal on the XM650E4 RA projectile. This test consisted of clamping the shell onto a spin stand and igniting the rocket motor. The temperature of the interior base wall was monitored by thermocouples. The results from the static tests are not available at the writing of this report.

B. Trisonde Data From TR 296

The results of the trisonde data, the yawing and spin histories, from TR 296 are shown in Figures 14 and 15, respectively. Since the excessive rotation of the ogive for TR 840 had severed the power leads, no trisonde data were obtained.

Figure 14 shows a plot of complementary solar aspect angle as a function of flight time. The plot shows that the projectile initially had a small bi-modal yawing motion. Both the nutational and the precessional components of the yawing motion appear to have damped by five seconds into the flight. At ten seconds, when the rocket motor initiates, the precessional component re-appears and, once more, quickly damps out. Near the summit, between 40 and 45 seconds, both modes of the yawing motion are quiescent. It is difficult to estimate whether the nutational mode is also excited at the time of motor ignition due to the noise superimposed on the yawsonde data. The large amplitude noise between 12 and 14 seconds of flight is a characteristic of the yawsonde data obtained at YPG that may be caused by the high noise-to-signal ratio of the transmitted data. This high ratio is a result of the position of the receivers with respect to the shell's trajectory.

Figure 15 shows a plot of spinsonde data as a function of flight time, phi-dot vs time. Since the frequency of the spinsonde VCO was higher than that for the yawsonde signal, distortions are minimized and the plot is nearly free of noise with the exception of the 12-to-14-second section. During the first ten seconds of flight, the projectile shows the expected monotonic reduction in the spin data. At ten seconds, when the rocket motor ignites, there is a sudden change in the trend of the spin curve. The value of phi-dot appears to remain constant around 108 rev/sec during the rocket burn although termination of this phase could not be determined due to the noise in the data. After the rocket burn-out, around 14 seconds, the spin of the projectile resumes its monotonic downward trend.*

**Recently, this spin behavior has been observed for other rocket-assisted projectiles. Appendix A contains some other examples.*

IV. SUMMARY

Two 8-inch rocket-assisted XM650E4 projectiles were instrumented to measure the interior temperature of the warhead cavity. One shell, TR 296, was fired from the 1/25-twist M110 weapon at Zone 7 while the second projectile, TR 840, was fired from the 1/20-twist M110A1 weapon at Zone 9. Both shell were launched with rocket on.

Due to high in-bore torque applied to the shell during the launch from the M110A1 weapon, the internal power leads of TR 840 were broken. Therefore, no data were gathered for this round. TR 296 transmitted both temperature and flight data as discussed in the report. The yawsonde results show a small bi-modal yawing motion that damps early in the flight. For the rest of its trajectory, the shell has very small yaw or no yaw at all. The spin data also indicate a normal behavior, with a short segment, during rocket burn, where the spin has a constant value.

The purpose of the temperature measurements was to determine the effect of rocket burning on the internal temperature of the warhead. Data from TR 296, Figure 13, indicate that there is approximately a 30-second time lag between the rocket ignition and initial rise in bulkhead temperature. The temperature of the bulkhead appears to be uniform, within the accuracy of the gauges, during the full flight. At the time of impact, about 83.5 seconds of flight, all gauges show about 8°C temperature rise to a final level of about 32°C.

REFERENCES

1. C.H. Murphy, "Effect of Large High-Frequency Angular Motion of a Shell on the Analysis of Its Yawsonde Records," Ballistic Research Laboratories Memorandum Report 2581, February 1976. AD B009421L.

2. W.H. Mermagen and W.H. Clay, "The Design of a Second Generation Yawsonde," Ballistic Research Laboratories Memorandum Report 2368, April 1974. AD 780064.

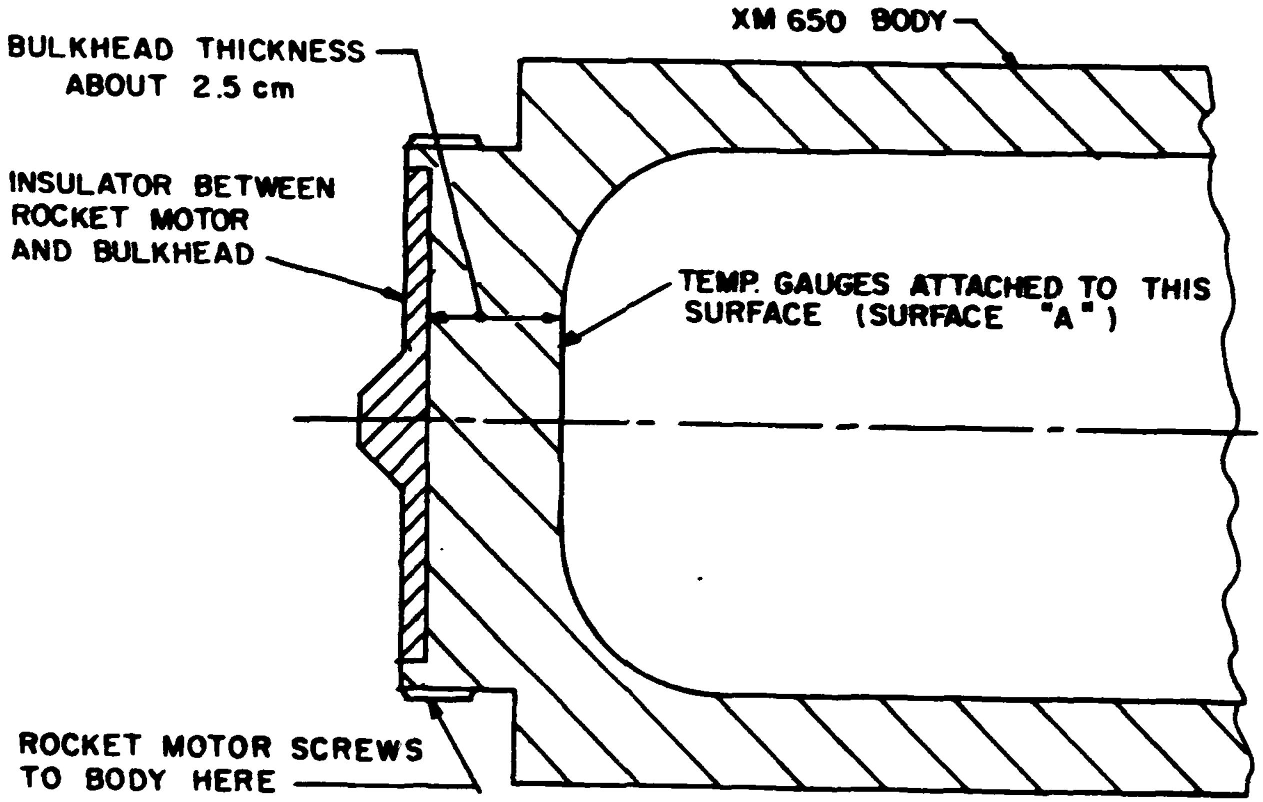
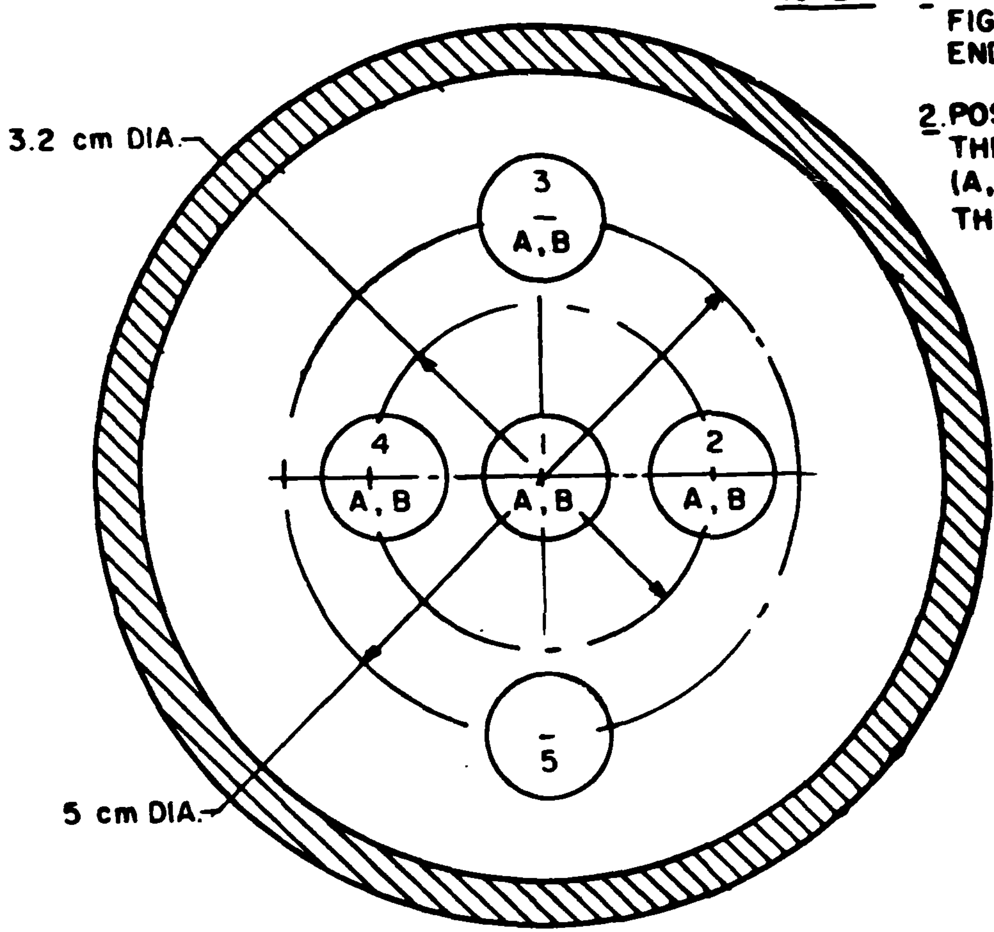


FIGURE 1. SKETCH OF XM650E4 SHOWING LOCATION OF TEMPERATURE SENSORS.



NOTES: 1. VIEWING SURFACE "A" IN FIGURE 1 FROM FORWARD END OF SHELL BODY

2. POSITIONS 1-4 HAVE TWO THERMISTOR GAUGES (A,B), POSITION 5 IS A THERMOCOUPLE

DETAIL: EACH POSITION

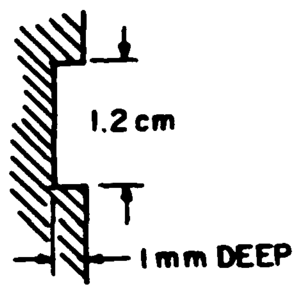


FIGURE 2. RELATIVE LOCATION OF THE THERMISTOR AND THERMOCOUPLE GAUGES.

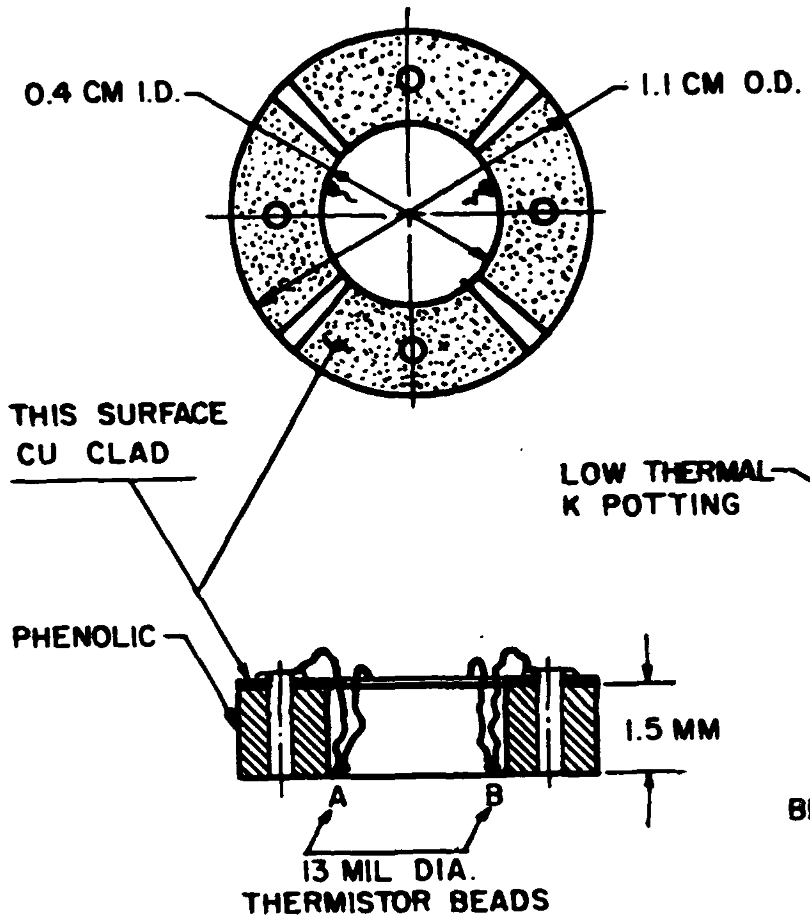


FIGURE 3A. THERMISTOR BEAD—PHENOLIC WASHER CONSTRUCTION.

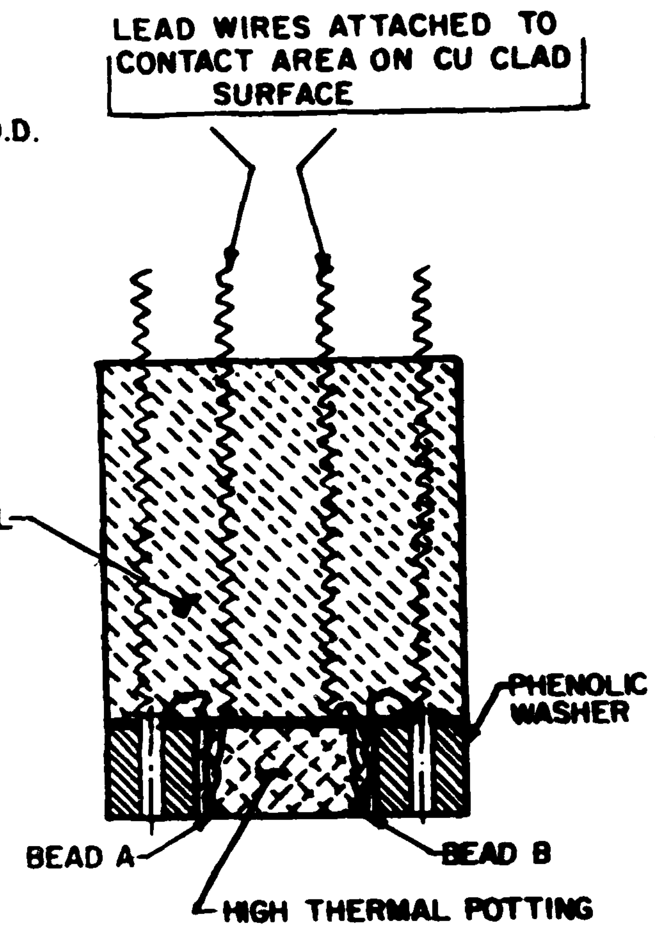


FIGURE 3B. SKETCH OF TEMPERATURE GAUGE MODULE.

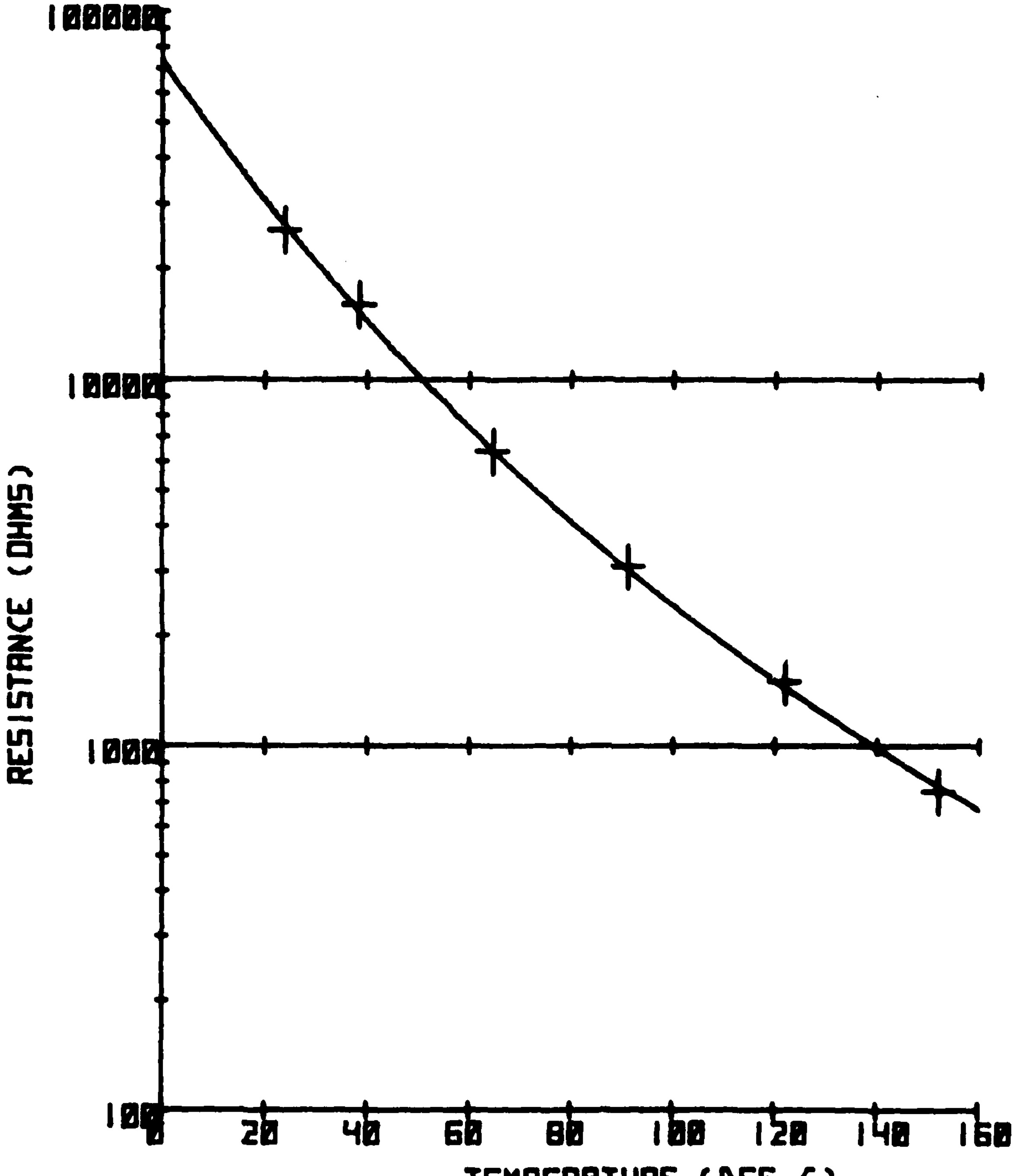


FIGURE 4. TYPICAL RESISTANCE — TEMPERATURE CALIBRATION FOR THERMISTOR GAUGE

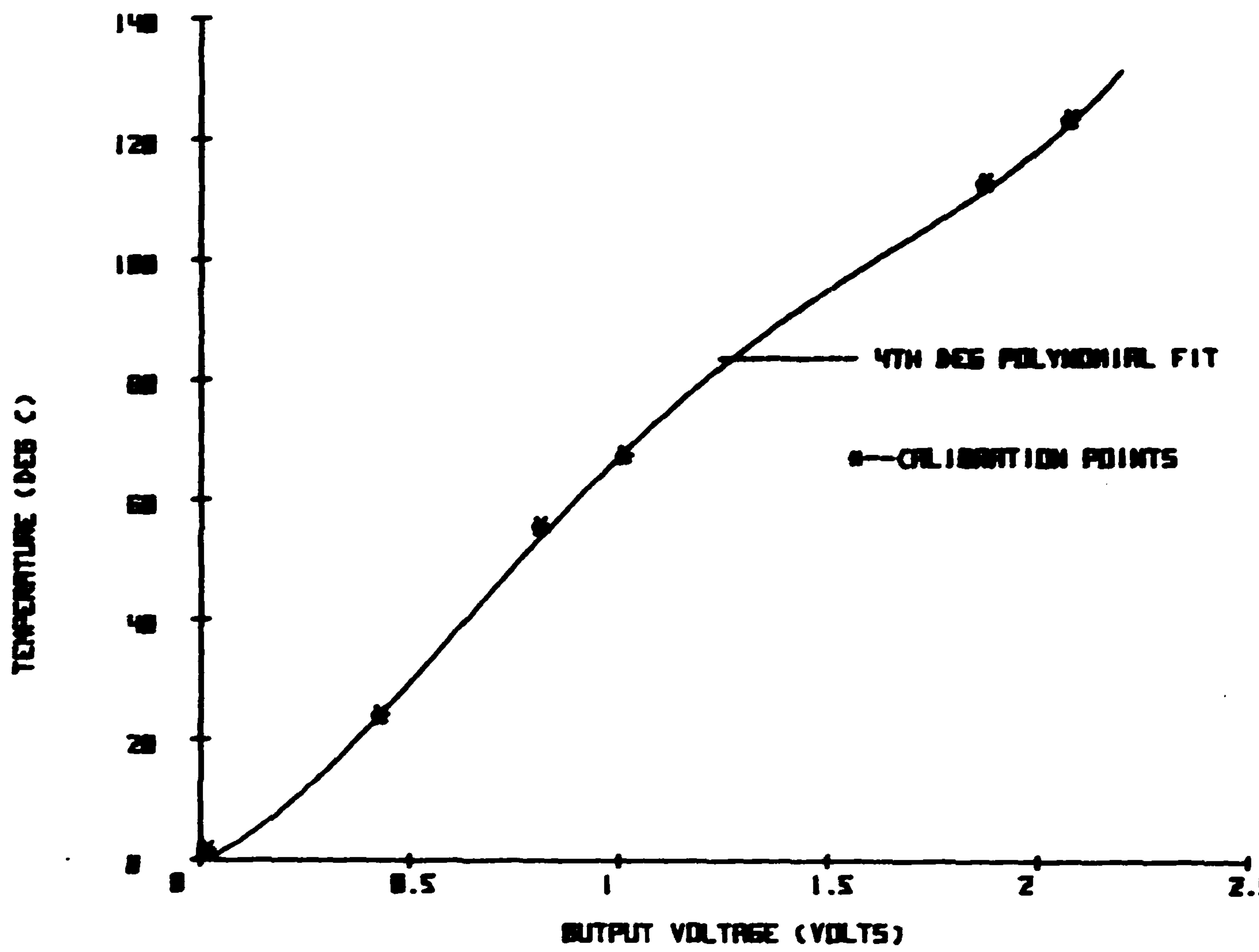


FIGURE 5. TEMPERATURE - VOLTAGE CALIBRATION FOR THERMOCOUPLE #2

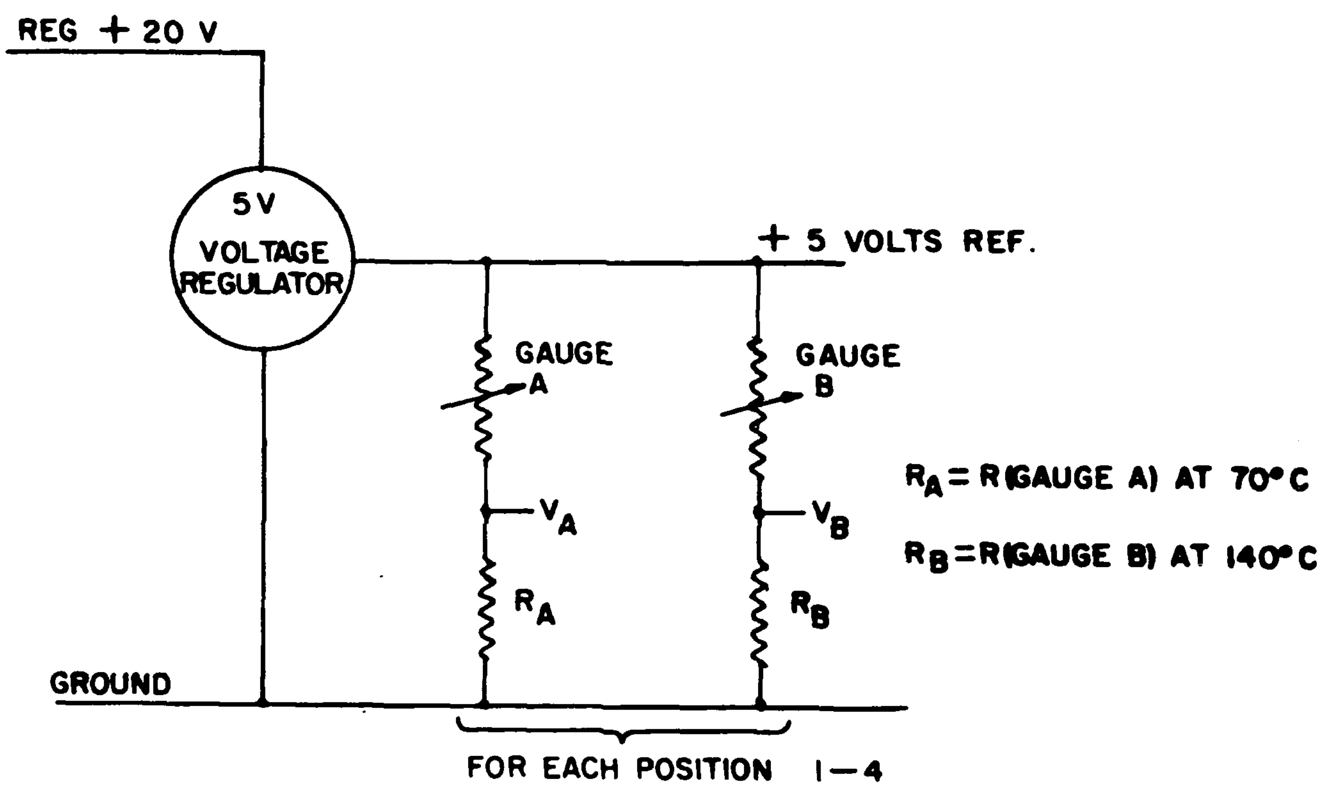


FIGURE 6. REFERENCE VOLTAGE DIVIDER CIRCUIT USED FOR THERMISTORS AT POSITIONS 1—4.

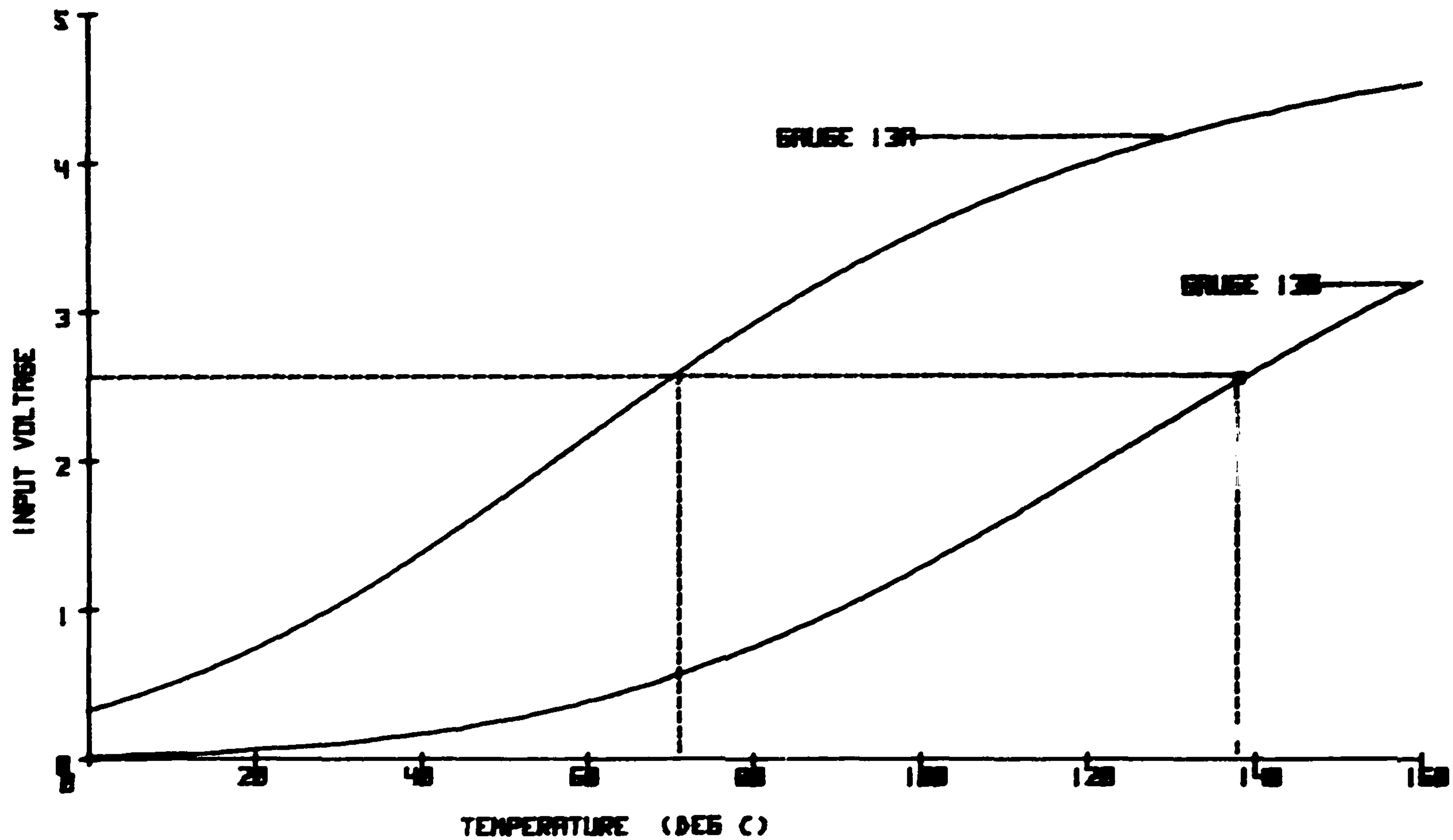


FIGURE 7. COMMUTATOR INPUT VOLTAGE VS TEMPERATURE FOR THERMISTORS

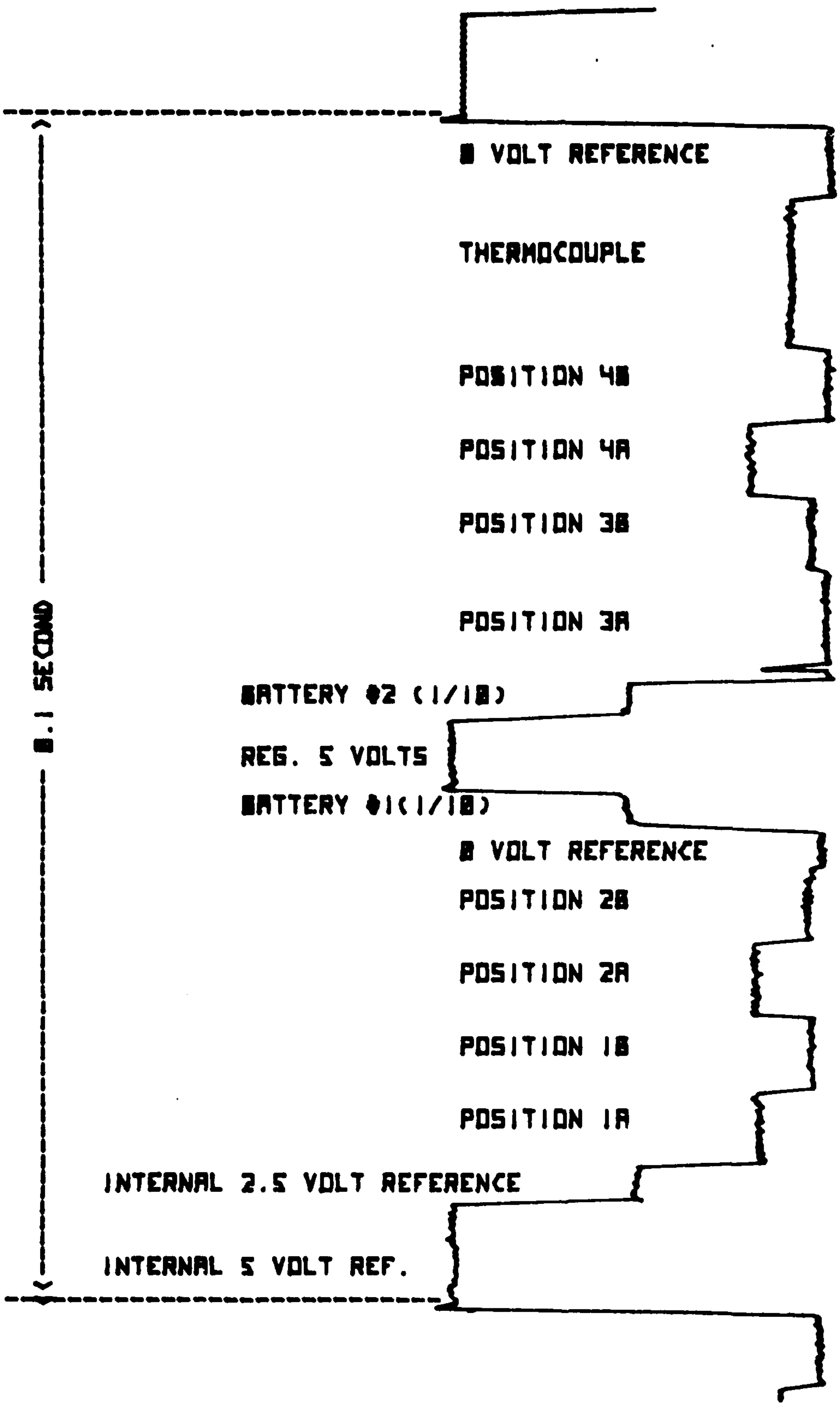


FIGURE 8. TRACE OF OSCILLOGRAPH RECORD FOR TR 296.

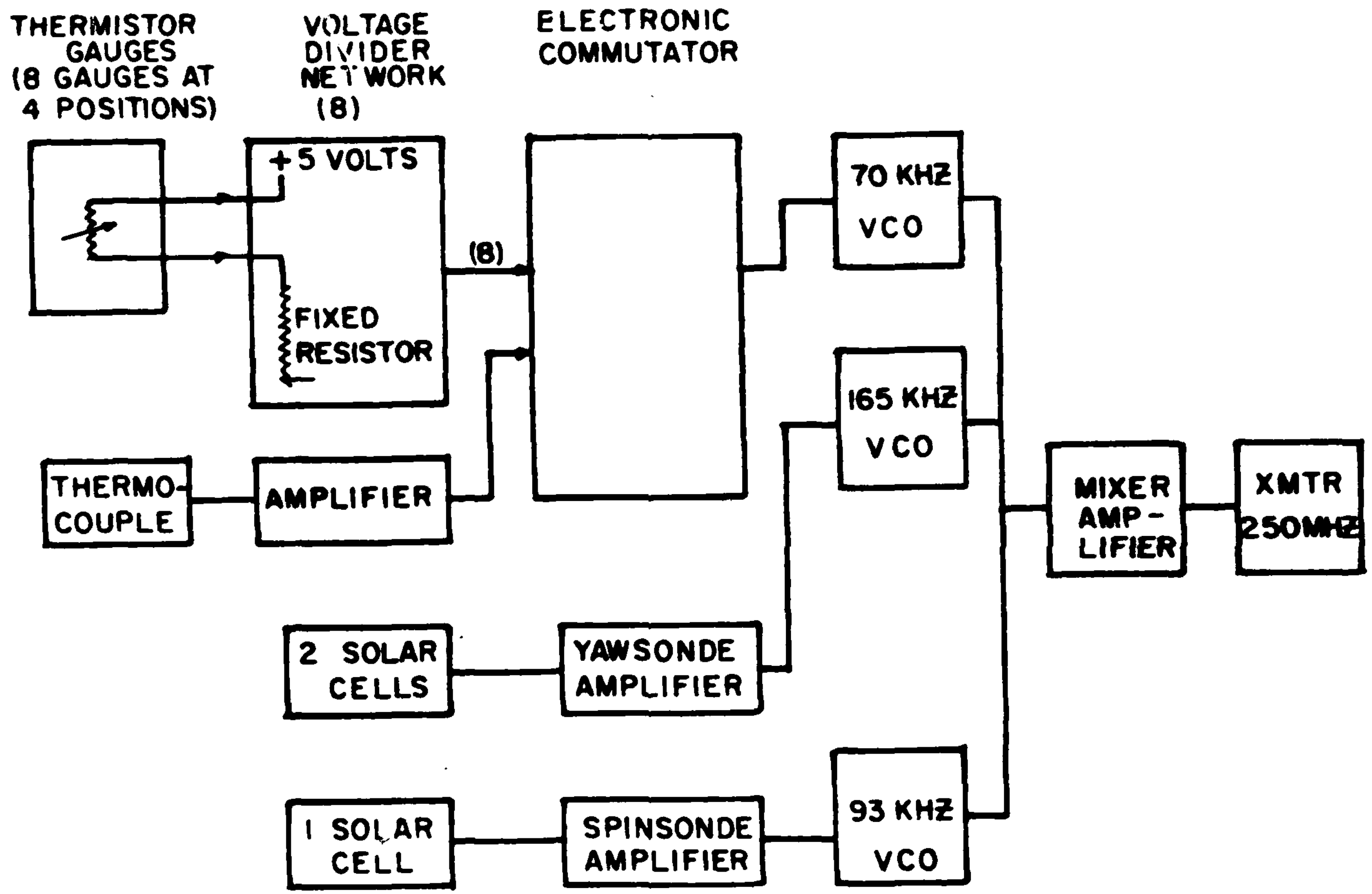


FIGURE 9. BLOCK DIAGRAM OF THE TELEMETRY PACKAGE

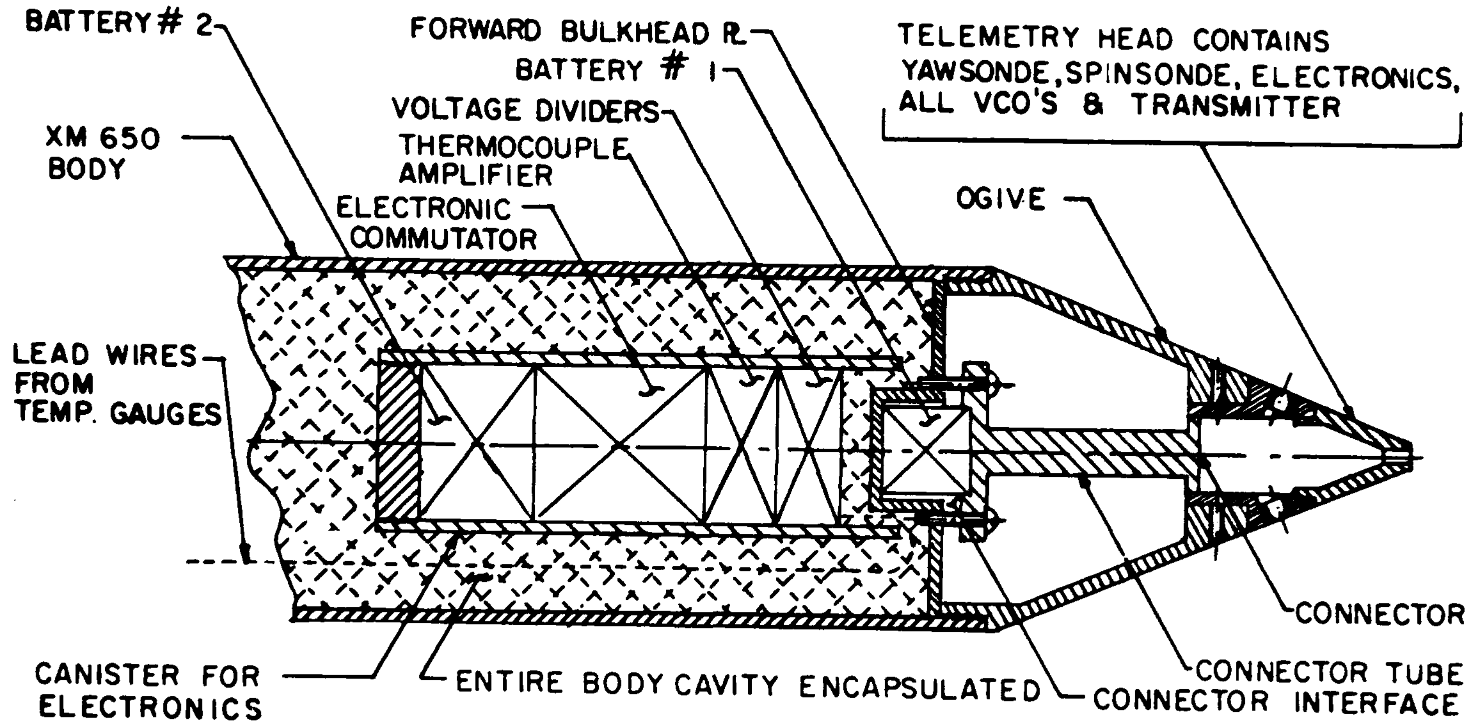


FIGURE 10. ASSEMBLED XM650E4 RA PROJECTILE INSTRUMENTED WITH TEMPERATURE SENSORS AND A TELEMETRY PACKAGE.

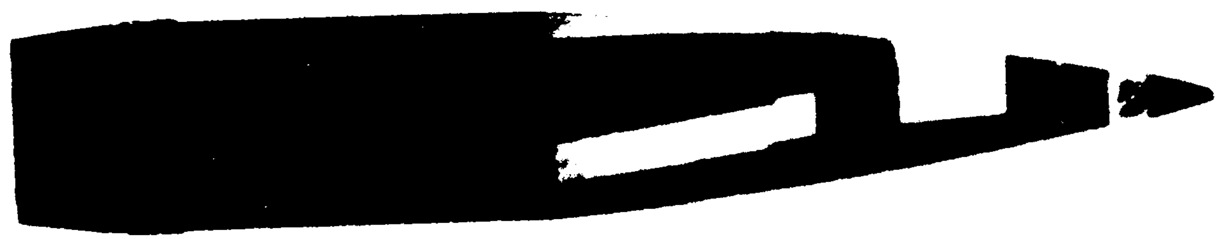


Figure 11. Smear Photograph of TR 296 (Launched From M110 Weapon)

Figure 12. Smear Photograph of TR 840 (Launched From M110A1 Weapon)

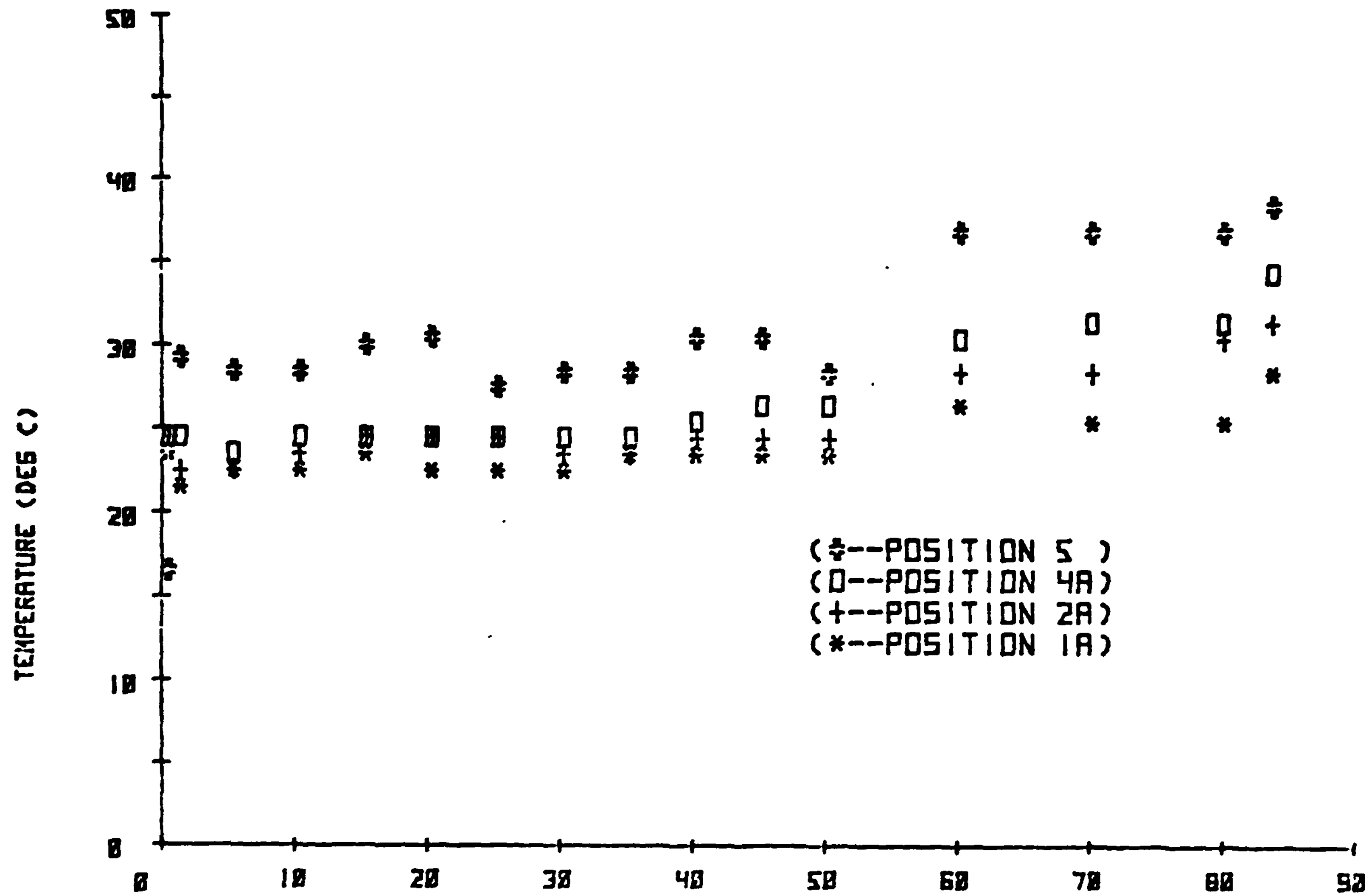


FIGURE 13. TEMPERATURE HISTORY FOR T.R.296 FROM POSITIONS 1,2,4,ANDS.

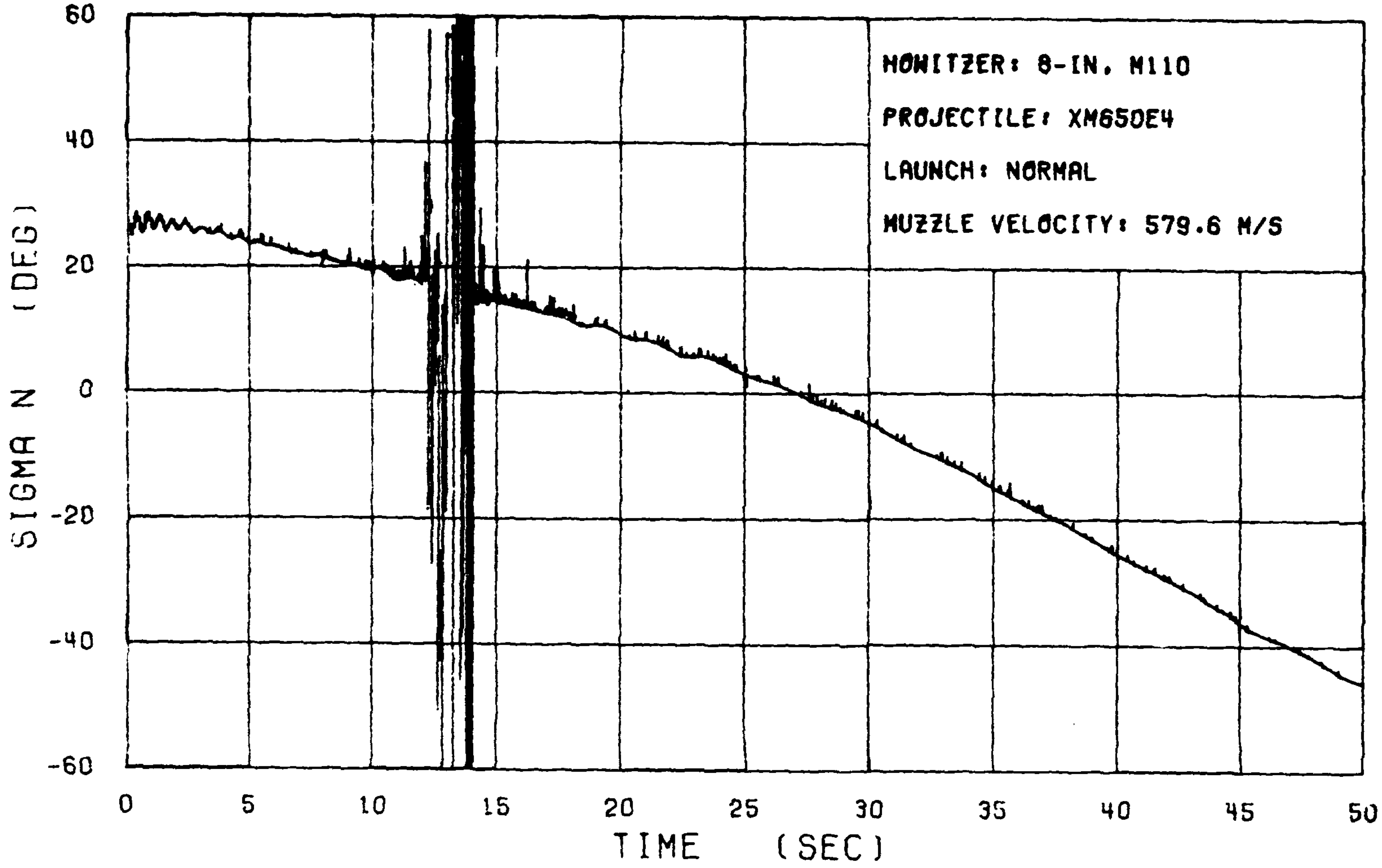


Figure 14. Sigma N vs Time for TR 296

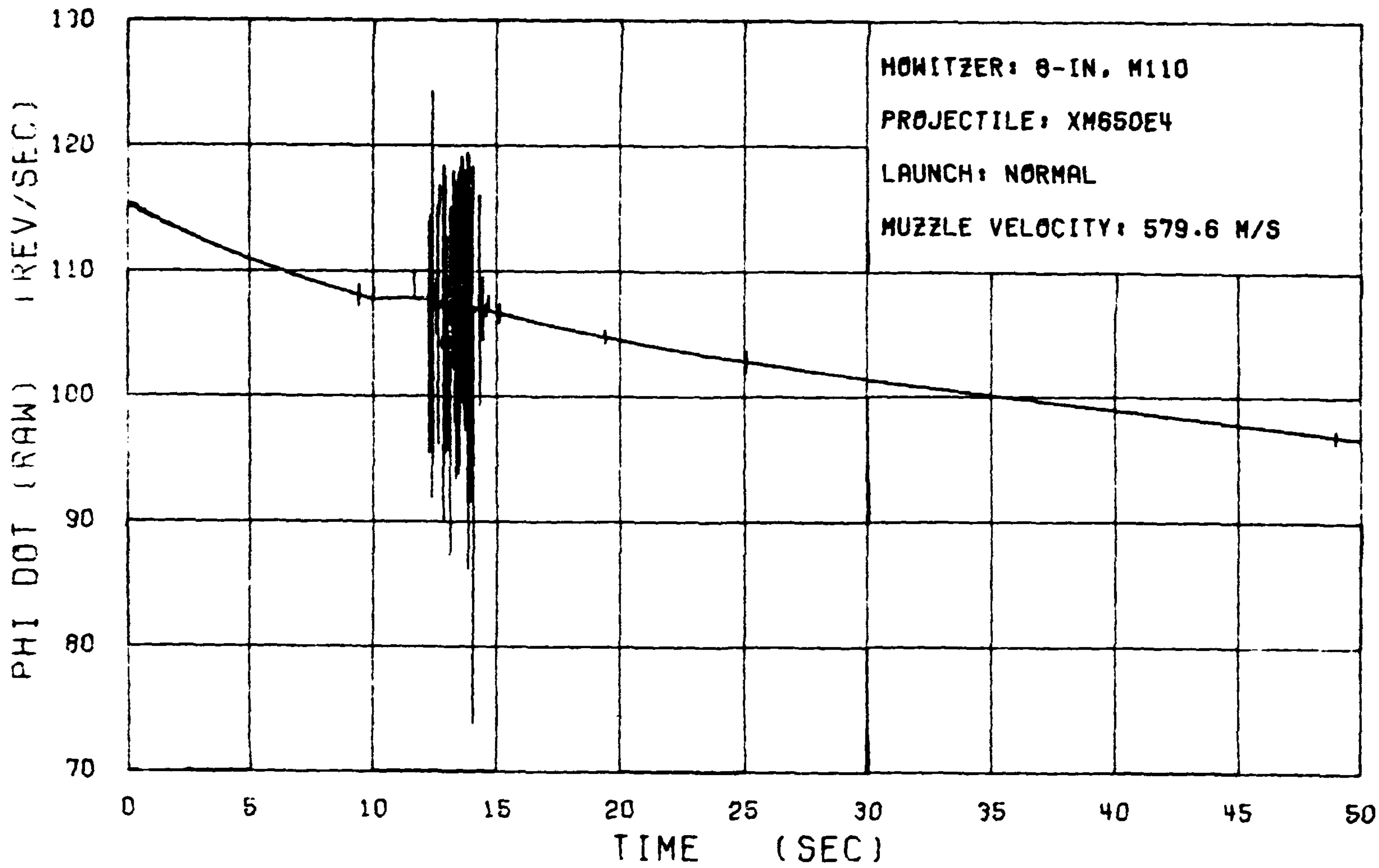


Figure 15. Phi Dot vs Time for TR 296

APPENDIX A

APPENDIX A. SAMPLE SPIN PLOTS FOR ROCKET ASSISTED PROJECTILES

Several additional examples of spin behavior for 8-inch rocket-assisted projectiles are presented in Figures A1-A4 of this Appendix. Test conditions for these rounds are given in Table A1.

TABLE A1. TEST CONDITIONS FOR SAMPLE 8-INCH ROCKET-ASSISTED PROJECTILES FIRED FROM M110A1 WEAPON

Date	BRL Number	Tube Round Number	Charge	QE
28 April 1977	1120	136*	Z9	750 mils
29 April 1977	1164	150	Z9 RA	729 mils
2 May 1977	992	162	Z9 RA	550 mils
3 May 1977	1198	173	Z9 RA	650 mils

**This round is included as a baseline for comparison with live rocket rounds.*

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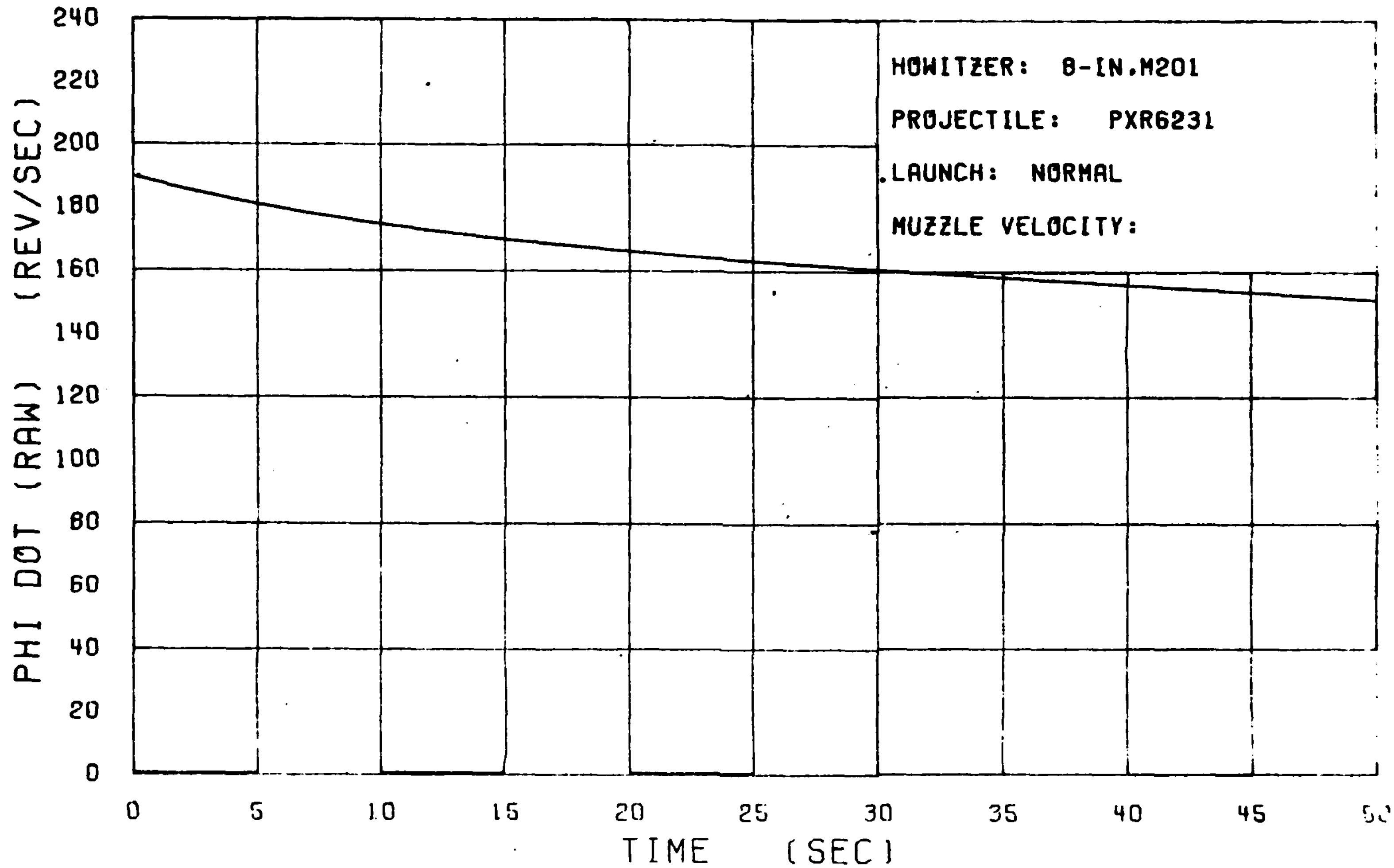

FIGURE A1. PHI DOT (RAW) VS TIME ROUND TR136

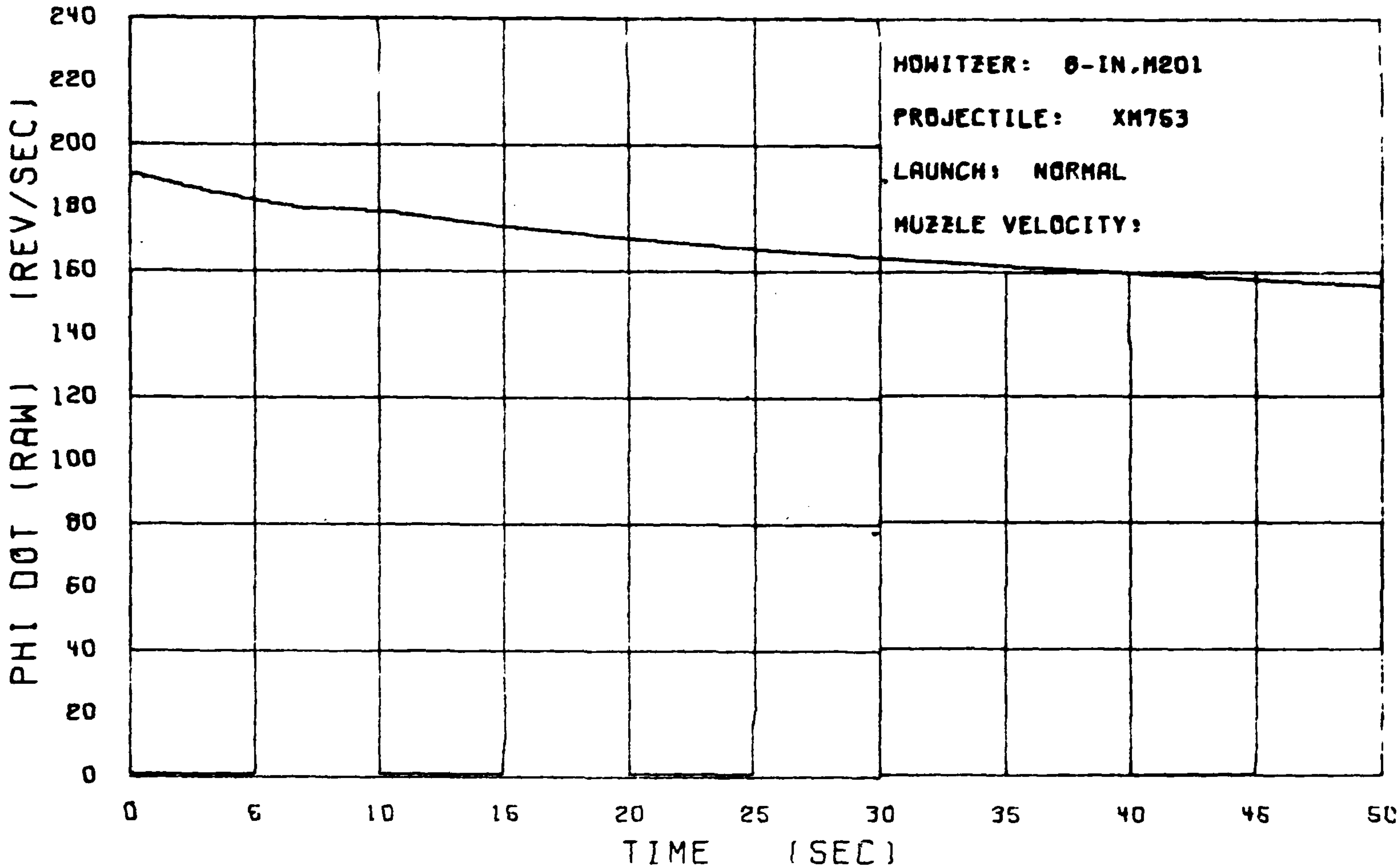

FIGURE A2. PHI DOT (RAW) VS TIME ROUND TR150

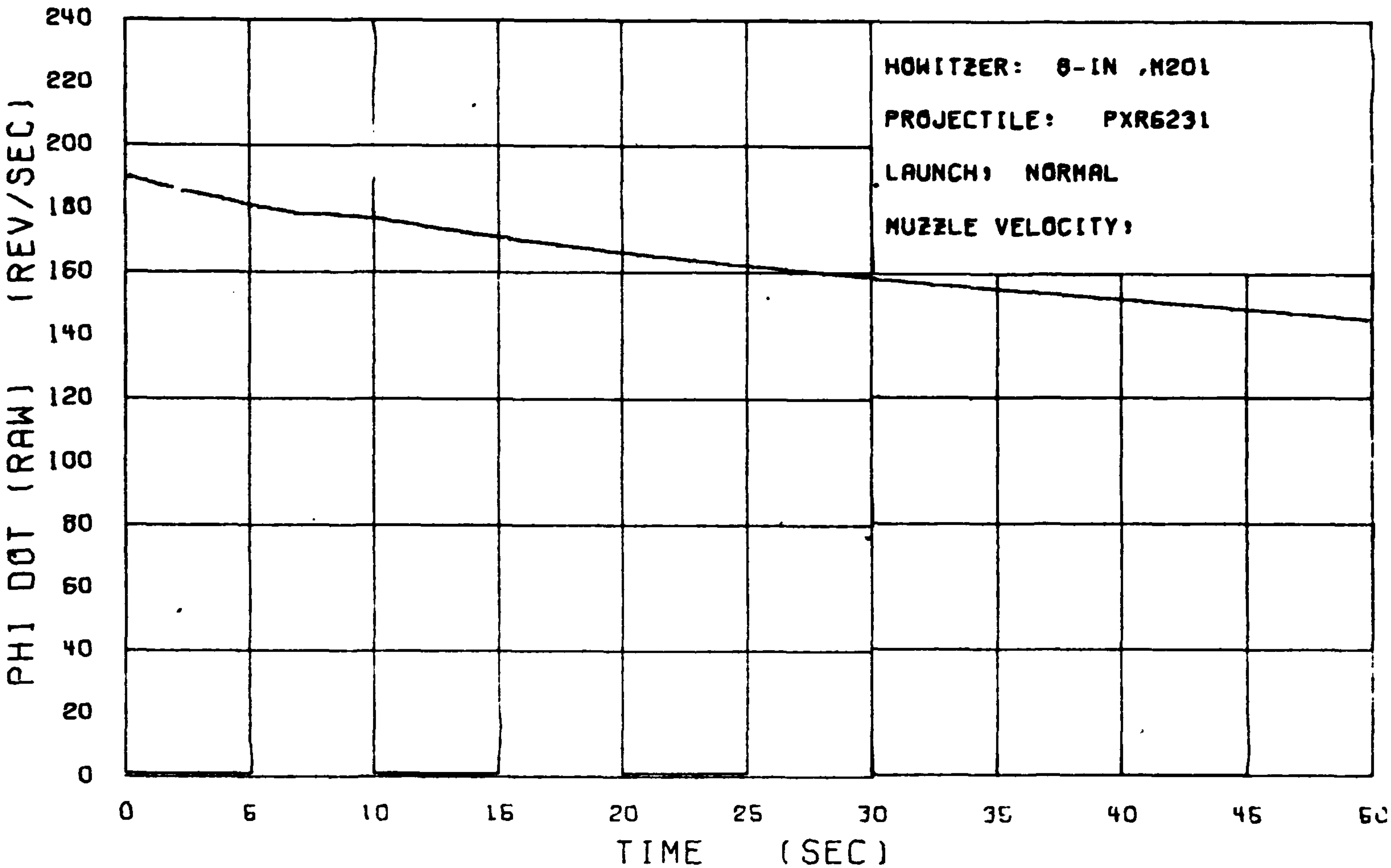

FIGURE A3. PHI DOT (RAW) VS TIME ROUND TR162

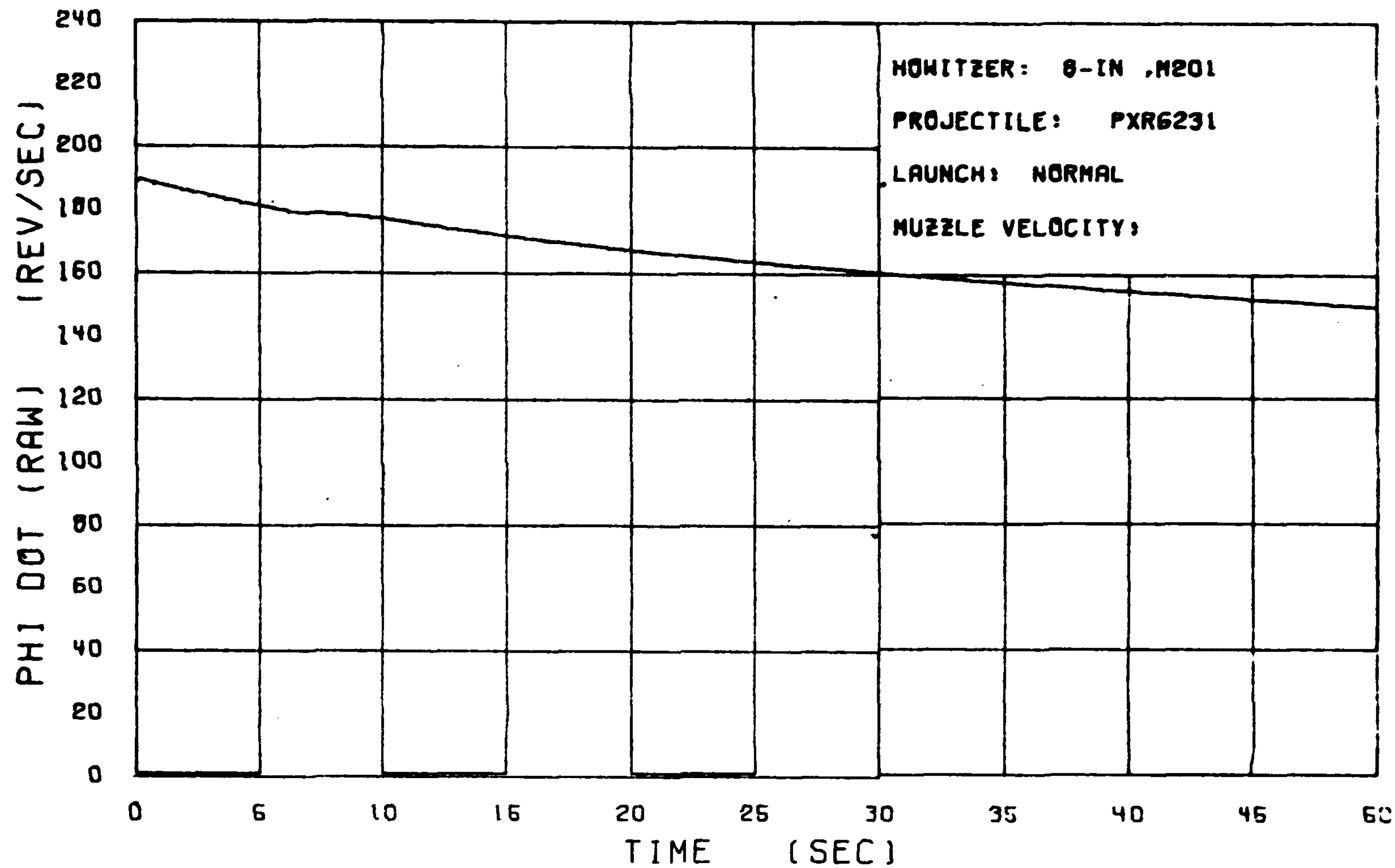

FIGURE **A4**. PHI DOT (RAW) VS TIME ROUND TR173

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